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CLEVITE
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ELECTRONIC RESEARCH DIVISION

CLEVITE CORPORATION
CLEVELAND, OHIO

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Project No. 303200

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STUDY OF THIN FILM LARGE AREA PHOTOVOLTAIC SOLAR ENERGY CONVERTER

Tenth Monthly Status Report
November 1, 1963 through November 30, 1963
(NASA Contract No. NAS7-203)

National Aeronautics and Space Administration
Western Operations Office

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Clevite Corporation
Electronic Research Division
Cleveland, Ohio

Study of Thin Film Large Area Photovoltaic
Solar Energy Converter

Tenth Monthly Status Report
November 1, 1963 through November 30, 1963
Contract No. NAS7-203

1. PRODUCTION OF EVAPORATED FILMS

Twenty evaporations (nos. 83 through 102) were completed during November. Twelve evaporations produced 96 CdS films on 1 in. x 2 in. glass substrates; the rest produced 8 CdS films on 4 in. x 4 in. H-Film substrates.

The quartz evaporation crucibles have been modified to allow insertion of a quartz shielded thermocouple into the evaporant. This will permit direct monitoring of the evaporator temperature and lead to closer control over the evaporated films.

A number of heater coil configurations have been tried to maintain a constant temperature profile during evaporation. The heater coil is a 3/4 inch diameter helix of tantalum wire. It is mounted vertically with the uppermost five turns spaced 1/32 inch apart and the rest of the turns (ten) spaced 3/32 inch apart. After two or three evaporations, the coil tends to sag under its own weight resulting in a change in the turns spacing. Attempts to retain the shape of the coil by packing it with a refractory fiber have not been very successful. Other attempts including a grooved boron nitride cylinder, quartz cloth packing and an attempt to groove a quartz cylinder were also unsuccessful. It is planned to replace the tantalum coil with a tungsten coil which will be stronger and to simply substitute new coils when sagging first becomes apparent.

2. PROCESSING OF PHOTOVOLTAIC CELLS

The efficiencies of standard glass backed cells are averaging very nearly two percent. Only a few fall outside the range of 1. 5 to 2. 5 percent. Those that fall below this range are always found to have some obvious deficiency such as abnormally high resistance or an imperfectly formed barrier layer. On the other hand, a few cells are always found with efficiencies significantly above this range indicating that the average cell obtained from the standard process is not yet the optimum cell. For example, the best cell obtained in November had an efficiency of 2.9 percent.

The average efficiency level fell to a nominal one percent, for a time, when a newly formulated CdS charge was put into use. This drop was traced to a deficiency in indium doping caused, apparently, by control failure in the sintering operation. A new boule with approximately the correct indium concentration has been obtained and the donor concentration in the evaporated films is being corrected by adjusting the ratio of doped to undoped material in the charge. One evaporation has been made with this latest boule and cells of 1.6 percent efficiency obtained. This is in the usual range of standard cells.

A good beginning has been made on constructing large area CdS photovoltaic cells on H-Film. Cells with efficiencies of the order of one percent and areas of 35 cm^2 have been made. Adhesion of the CdS film to H-Film is good.

Photovoltaic cells or batteries on H-Film are to be made exclusively as soon as mounting frames, masks and other hardware now being fabricated are available. The basic pattern will be a 3 x 3 cell layout on a 4 inch x 4 inch H-Film substrate. Each cell will be approximately 3/4 inch square. Connections will be made in series or parallel or both, as required.

Properties of cells fabricated during November are summarized in Table I.

Table I. Properties of CdS Photovoltaic Cells

Cell No.	V_{oc}, Volts	I_{sc}, mA	V_{mp}, Volts	I_{mp}, mA	Active Area, cm^2	Efficiency, percent	Fill Factor
82-1	0.47	79.0	0.33	61.0	7.4	2.7	0.542
82-4	0.46	37.0	0.35	28.2	6.6	1.5	0.581
82-7	0.50	44.0	0.40	36.0	7.4	2.0	0.655
83-5	0.42	50.0	0.28	28.0	7.4	1.1	0.374
83-6	0.42	28.0	0.30	18.5	8.0	0.7	0.472
83-8	0.42	40.0	0.32	30.0	8.6	1.1	0.571
84H-1**	0.46	63.5	0.35	53.0	21.6	0.9	0.635
86-1	0.51	48.5	0.38	34.0	5.9	2.2	0.522
86-2	0.49	36.0	0.38	27.2	6.9	1.5	0.585
86-4	0.47	32.3	0.35	24.5	5.1	1.7	0.460
86-7	0.47	14.6	0.34	9.5	7.2	0.5	0.470
87-1	0.51	68.3	0.37	56.0	7.0	2.9	0.595
87-6	0.46	34.0	0.35	24.0	8.0	1.0	0.537
87-7	0.51	49.5	0.38	39.0	6.4	2.3	0.586
87-8	0.51	34.0	0.39	25.5	3.6	2.7	0.573
88-1	0.49	25.0	0.39	22.2	7.8	1.2	0.706
88-2	0.49	22.5	0.38	19.0	6.4	1.1	0.655
88-8	0.45	27.0	0.34	21.5	7.3	1.0	0.602
89H-A	0.46	59.5	0.29	45.0	9.3	1.4	0.477
89H-B	0.45	45.0	0.32	36.0	8.6	1.4	0.570
89H-C	0.46	54.0	0.31	43.0	8.4	1.6	0.533
89H-D	0.46	42.5	0.32	34.0	9.0	1.2	0.556
89H-1*	0.45	178.0	0.30	132.0	35.3	1.1	0.494
90H-1	0.45	132.0	0.31	97.0	34.8	0.9	0.506
91H-A	0.44	45.0	0.33	33.0	9.3	1.2	0.551
91H-B	0.44	35.0	0.30	27.0	9.3	0.9	0.526
91H-C	0.43	58.5	0.30	45.5	9.9	1.4	0.544
91H-D	0.44	51.0	0.30	39.5	9.0	1.3	0.529
91H-1*	0.43	175.0	0.27	130.0	37.6	0.9	0.466
92-4	0.45	74.5	0.31	56.0	8.4	2.1	0.517
92-5	0.45	36.0	0.35	30.0	8.4	1.2	0.647
92-7	0.37	44.0	0.25	32.0	8.1	1.0	0.491
93-3	0.43	25.0	0.32	21.0	8.0	0.8	0.625
93-6	0.39	79.5	0.23	50.0	8.7	1.3	0.371
94-2	0.51	19.7	0.39	18.5	7.1	1.0	0.717
94-4	0.41	77.5	0.27	54.0	8.4	1.7	0.459
95H-1	0.45	47.0	0.30	38.0	44.2	0.3	0.540
96-3	0.48	22.5	0.38	20.0	8.6	0.9	0.704
98-2	0.48	21.7	0.38	19.3	7.7	1.0	0.705
99H-A	0.43	11.0	0.31	8.3	9.0	0.3	0.545
99H-B	0.46	17.0	0.37	14.0	9.3	0.6	0.663
99H-C	0.46	15.0	0.35	12.6	9.0	0.5	0.639
99H-D	0.46	20.8	0.36	17.8	8.4	0.8	0.670
99H-1*	0.40	44.0	0.27	32.0	35.7	0.3	0.490
101-3	0.49	17.0	0.40	14.5	8.6	0.7	0.697
101-5	0.47	46.0	0.36	35.8	8.9	1.4	0.596
101-7	0.48	40.5	0.35	40.5	7.6	1.6	0.730
102-5	0.45	18.5	0.32	13.0	4.4	1.0	0.461
102-6	0.43	13.6	0.33	10.0	9.1	0.4	0.564

**H in a number means an H-Film substrate. Otherwise the substrate is glass.

*Cells, A, B, C and D connected in parallel. Common CdS layer and separate barrier layers.

3. MEASUREMENTS

Cell degradation studies are continuing. One cell, 88-5 has been kept in a vacuum dessicator for more than 22 days, being removed only long enough to measure its efficiency. Data for this cell are shown in Table II. It is interesting that the open circuit voltage decreases and short circuit current increases with time.

Table II. Degradation of Cell 88-5

Time in Days	V_{oc}, Volts	V_{sc}, mA/cm^2	Efficiency, Percent	Fill Factor
0	0.47	8.1	2.2	0.59
4	0.45	7.9	2.0	0.55
6	0.41	7.9	1.7	0.53
8	0.41	8.8	1.7	0.49
11	0.40	9.2	1.7	0.47
14	0.40	9.1	1.6	0.44
15	0.39	9.1	1.5	0.43
19	0.39	9.2	1.5	0.43
20	0.39	8.9	1.5	0.43
22	0.40	9.2	1.6	0.44

Much more data of this type is needed before conclusions can be drawn. These experiments are in progress.

It was mentioned in the 4th Quarterly Report that various mathematical models of ideal photovoltaic cells were being studied in the hope of gaining further insight into the behavior of CdS photovoltaic cells. Of particular importance is the dependency of cell behavior on series and shunt resistance. One model being investigated has current-voltage characteristics given by

$$i = -i_o\left(e^{\frac{-q}{AKT}(V-iR_s)} - 1\right) + i_L + \frac{V-iR_s}{R_{SH}} ,$$

where i_o and i_L are the reverse saturation current and light generated current respectively, R_s and R_{SH} are the internal series and shunt resistances respectively of the cell and the other symbols have their usual meaning. This expression, being transcendental in i, V and R_s is exceedingly difficult to evaluate except in the limiting cases of $R_s = 0$, $R_{SH} = \infty$. It is, therefore, impossible to separate the effects of R_s, R_{SH} and A unless the equation can be solved numerically for particular values of the parameters. This will be done on Clevite's computer.

4. ALTERNATE METHODS OF PRODUCING FILMS

Early work on lead sulfide mirrors was reviewed. A patent, "Method of Making Colored Mirrors," issued as Patent No. 2,411,955 on December 3, 1946 to W. H. Colbert and W. L. Morgan describes a process for making a lead sulfide mirror and mentions that sulfides of certain other metals, including cadmium, also produce mirrors but no formulas are listed.

Experiments showed that Colbert's recipe was not directly applicable to the formation of CdS mirrors. Modifications were introduced and a CdS mirror was successfully deposited on the walls of the test tube and a strip of H-Film contained therein. The film on the glass was well adherent and could not be rubbed off. The deposit on H-Film was fluffy and did not adhere. It appeared that the H-Film was attacked by the reacting solutions.

Subsequent attempts to deposit PbS mirrors on H-Film were unsuccessful.

It has been determined that concentrated NH_4OH, NaOH and H_2SO_4 readily attack H-Film while HCl and HNO_3 do not.

Current experiments readily produce adherent, good appearing, CdS films on glass. Deposits on H-Film have been obtained but these are usually very thin and/or non-uniform. Experiments on H-Film will continue.

5. PLANS FOR NEXT MONTH

Work will continue as described. The effort on cell degradation will be increased and it is expected that 3 x 3 arrays of CdS on H-Film will be obtained.

6. PERSONNEL

Time devoted to this project by principal technical personnel and others during the month of November follows:

Personnel	Hours
W. J. Deshotels	131.0
F. Augustine	155.0
J. Koenig	155.0
Others	402.5
Total	843.5

7. EXPENDITURES

Actual Costs to November 30, 1963	$144, 600
Estimated Costs for December, 1963	9, 600

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